43rd Annual Fuze Conference
Dr. Peter A. Bukowick
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Fuze Reliability

Slide 1: Title slide

Thank you, Len. It is a pleasure and an honor to be speaking to the fuze conference today. Fuzing is one of the core technologies where I work; more importantly, fuze reliability is critical to our military capability.

My purpose here today is to offer some thoughts on a common interest we all share as users of fuze, developers, and manufacturers; namely, fuze reliability. Reliability provides the soldiers, sailors, and airmen who depend on our work with fuzes that enable them to accomplish the mission.

The mission of a fuze can be described in simple terms, yet this belies the complexity required to accomplish seemingly contradictory tasks, namely:

Slide 2: Mission

- The fuze must be safe for the user—that is, safe to manufacture, store, handle, and deliver.

- At the same time, it must be lethal to the enemy.

Our common goal as members of the fuze community is to provide systems that accomplish this double mission—100 percent of the time. It is safe to say we have not yet achieved this goal. Before we look forward to100 percent reliability, let's look backward to where we have been.

In 1856, Commander Dahlgren made the observation that without a good system of fuzes, artillery projectiles would be "bodies without souls." I would agree with that observation to a point, but would rephrase it as "bodies without minds." The commander was referring to the technological evolution from solid projectiles to bursting shot and shells. Just as it is today, precise timing was essential then. With case shot traveling 1200 feet per second, a quarter of a second timing error would result in a burst point error of 100 yards. (Ideally, these rounds were to burst 50 yards in front of the enemy.)

In fact, the essence of the fuze, the real purpose for a fuze, lies in the need for weapons to "think," to take autonomous action once they have been released by their users. The fuze must know whether it is still in friendly hands or being delivered to enemy hands.

The advance of other aspects of military technology has been matched by the evolution and refinement of the fuze. The ability to project weapons to greater distances, and thus greater standoff from "harms way," means the projectiles or weapons need to function autonomously well after they have been released. A certain complexity in the warhead is also implied.

Slide 3: Spanish 16" Pedrero (1788) "Basket of Stones"

Rocks, sticks, clubs, arrows, and other kinetic energy rounds do not need fuzes. The stone mortar, vintage late 18th century, was one such delivery system for kinetic energy projectiles. Round stones, roughly the size of a man's fist, were loaded into a basket and lowered into the bore of the stone mortar. The primitive charge was fired into the air against a defensive position at close range. The stones would descend on the enemy; brainless projectiles, no fuzes.

The American Civil War marked a transition from traditional weaponry to many modern, more intelligent weaponry concepts. Some people have referred to the American Civil War as the first modern war because of innovations such as the submarine, machine gun, military rocket, and a proliferation of fuzed projectiles. So many variations of guns, projectiles, and fuzes existed that the military leaders and logisticans of both sides lamented the confusion. They called for a reduction of the number of variants and the standardization of fuze setting procedures. If this sounds familiar, it is. We are currently struggling with the same issues of fuze commonality across weapon types and NATO standardization for setting of all types of fuzes.

Slide 4: Wooden powder fuze and time gradation + table of fire

The first projectile time fuzes consisted of tapered cylinders of wood, hollowed out and packed with a composition of gunpowder moistened with whiskey or alcohol. When dry, the rate of burning would be determined by experiment and marked on the fuzes in the lot.

The gunner, after learning the range to the target, determined the elevation and flight time from a table similar to the one shown. A certain amount of mathematical skill was expected in order to interpolate from the ranges given in the table. The fuze, marked in tenths of inches, was set by cutting it to the proper length with a fuze saw: the first fuze setter. You can tell this soldier is new to the job: he still has both hands. As you know, accuracy and repeatability are absolutely essential to the effectiveness of time fuzed weapons. This process did not have it. The burn rate of the composition packed into the wooden tubes was variable. The packing resulted in uneven stratification of the powder. The brand and proof of the whiskey used in the process may also have affected the outcome.

Slide 5: Paper fuzes, including papers

To resolve this problem and improve fuze repeatability, North and South both upgraded this primitive approach by developing the paper fuze. Paper fuzes were factory made and color-coded: yellow burned five seconds to the inch, green seven, and blue ten. The Union ordnance department decreed that only the Frankford Arsenal could manufacture paper fuzes. This was done to ensure a consistent controlled process, with uniform material to ensure a repeatable product.

The Confederate ordnance bureau could not afford this luxury, and the variability of their fuzes, in comparison to those of their Union counterparts, was a regular source of frustration to the Confederate artillery. Whether with wooden or paper fuzes, however, the job of the Civil War artilleryman was dangerous. Both wooden composition and paper fuzes continued to suffer from the shocks of the field environment, which tended to break up the solid composition, allowing fire to penetrate too quickly to the main charge, with disastrous, gun exploding consequences.

Slide 6: Federal and Confederate Bormann time fuze and shells with fuzes installed

The next advance in the time fuze was named after its inventor, Belgian Army Captain Charles G. Bormann. The Bormann time fuze was a Belgian state secret for many years, until it was leaked in the 1850s.

This fuze, like the paper and wood fuzes, was placed into a hole in the cannonball. The hollow inside the cannonball was filled with explosives. The cannonball had to be correctly loaded into the gun barrel—fuze to the front. If the cannonball was not correctly oriented, the fuze would initiate prematurely. The Bormann fuze was also a pyrotechnic delay fuze, but the burn consistency was much more repeatable, given proper process control. As an added benefit, the setting process was quicker. To set the fuze, the gunnery crew would punch a hole in the soft pewter face of the fuze. The number indicated the time required to burst. Setter technology had evolved from the fuze saw to the hole punch. The powder inside the fuze was ignited through the hole by the propellant flame as it swept around the projectile.

The Bormann fuze became the Union standard for spherical case shot but ended up being a nightmare for the Confederacy. After large quantities of their ammunition had been fuzed with the Bormann fuze, field reports indicated that fully four-fifths of the Confederate Bormann fuzed shells exploded prematurely, and very many of them in the gun. A lengthy investigation found the trouble to be in the sealing of the horseshoe channel containing the composition. The shock of discharge would unseat the horse-shoe shaped plug that protected this channel and allow the flame from the propellant to bypass the composition, reaching the charge of the shell prematurely. As the result of infantry casualties from their own guns during the Battle of Fredericksburg, the Confederacy decided to abandon the Bormann fuze. Artillery reverted to the older, but easier to manufacture, paper fuze.

As the Civil War progressed, the use of rifled guns became more prevalent due to their increased accuracy and range. The projectiles for these new guns evolved from spherical case shot to the more familiar cylindrical shells we have today. This projectile shape meant the impact point of the shell could be better predicted, compared to spherical shells or cannonballs. This fact lead to a new type of fuze called the percussion fuze, or as we would call it today, the impact fuze. These fuzes were sometimes combined with time fuzing pyrotechnic delays, and thus the combination fuze was born. This fuze could be set for time or impact, with each function usable separately or in combination.

Slide 7: Armstrong E fuze

Dozens of these fuzes proliferated during the conflict, but the most successful design was the Armstrong “E” Fuze, so named because it took five revisions to get it right, and “E” is the fifth letter of the alphabet. The Armstrong E fuze was fairly reliable and remained in British Army service until the 1890s.

The advent of World War One generated another flurry of technological advances. Gone were the old spherical case shot rounds. Safety became a much more achievable and required function.

Slide 8: Mark V point detonating fuze

A good example of this design for safety is provided by the Mark Five point detonating fuze used in the seventy-five millimeter guns of the day. This design was adapted from the French, with the American addition of the interrupter for extra safety. While the shell using this fuze was being accelerated in the gun bore, the interrupter would remain in the safe position, blocking the explosive train from premature function and making the round bore safe. Once outside the muzzle, the interrupter withdrew—as acceleration ceased—to allow the explosive train to propagate.

Fuze technology continued to progress from strictly pyrotechnic timing to mechanical "clockwork" timing, and eventually encompassed proximity fuzing. The proximity fuze becomes possible when you can instill enough intelligence in the fuze to establish its burst point not in reference to "where it has been," but rather in reference to "where it is going." The explosion of electronic technology in the mid and late twentieth century has enabled us to continuously expand the autonomous decision-making capability of the fuze.

Slide 9: Variable Time (VT) fuze

The first radio frequency artillery fuze was developed during World War Two. William T. Moye, historian for the U.S. Army Research Laboratory, has said, "Its development ranks with the maturation of radar and the atomic bomb as the major scientific achievements which contributed to the allied victory."

The variable time, or VT fuze (so named to conceal its true proximity function), was developed by Division Four of the National Defence Research Committee (the NDRC) under the leadership of Dr. Alexander H. Ellet and Harry Diamond. The major challenge was to develop sensors that could withstand the high-g forces of gun launch. There were smaller challenges, too. Wax often disappeared from the fuzes because the soldiers found that it made good chewing gum. The VT fuze marked the beginning of the modern era of electronic fuzing, and its production in the mid 1940s occupied much of the U.S. industrial capacity in both electronics and plastics. Its impact on the enemy was devastating, even though it was fielded late in the war. General Patton wrote "…the new shell with the funny fuze is devastating…. I think that when all armies get this shell we will have to devise some new method of warfare. I am glad that you all thought of it first."

Slide 10: Family of current fuzes

The VT was the forefather to the current family of high performance projectile fuzes. Interestingly enough, today we work to standardize to a small compatible family of fuzes, just as our Civil War predecessors did 140 years ago. The assortment of point detonating, time, and proximity fuzes has found a hybrid offspring in the Multi-Option Fuze for Artillery, or MOFA. The M762 is today's primary time fuze; and the Mark 399 is the standard fuze for military operations in urban terrain.

Throughout this brief survey of fuze history I have concentrated on cannon projectile fuzing because of its long and well documented technoloby. The technological growth of fuzes, however, has impacted almost all devices utilizing a warhead—from submunitions and hand emplaced weapons to bombs and missiles. The impact of fuze effectiveness, including safety, reliability, and repeatability, has been crucial to our warfighters in the past. It will be even more so in the future. When I began, I mentioned the objective of delivering exceptional reliability in our fuzes. What progress has been made in the last century and a half? Although data is sparse as we move further into the past along the fuze timeline, there are some known facts.

Slide 11: Comparative fuze table

During the siege of Petersburg, fuze reliability data was kept for various Union fuzes over a nine-month period during 1864 and 1865. The range in reliability is surprising, with the best fuzes performing at 85 percent and the worst at 53 percent. We have improved, as can be seen from more recent reliability data taken from a mechanical time fuze and a more modern electronic time fuze. We now need to look forward and establish our goals for the future as we strive for continuous improvement in quality, in repeatability, in reliability.

Slide 12: Fuze quality path

To achieve these goals, we can use the Fuze Quality Path, a derivation of Quality Functional Deployment, or QFD. It is a sequence of four matrices or phases, each essential to final fuze performance. I'll briefly describe each phase.

The first phase is an early and clear understanding of fuze requirements. We have made good progress in our working together as Integrated Product Teams, or IPTs. We need to continue this, starting it even earlier in the process, ensuring that the user's need is clearly met, documented, and communicated to the developer and producer.

With a clear requirement in mind, our next challenge—phase two— is to ensure that this requirement is met, with margin. In effect, QFD allows us to perform a sensitivity study on our fuzing system. This in turn identifies and prioritizes the key parameters that must be carefully tested and monitored during the development process to ensure that the design margin is inherent in the new fuze. This is the single biggest challenge to all of us in the fuze community today: identifying the correct system performance metrics early, adjusting them if required during Engineering and Manufacturing Development, and tracking them relentlessly throughout the whole process.

Phase three translates the critical part characteristics into critical process parameters. We select the best processes for part manufacture and assembly and identify the parameters that we must control through production. Analyzing the coefficients of variation and the process capability of the key steps in the process improves the repeatability of the fuze.

What we've learned in the first three steps can now be fed into phase four, production planning. This is where all of the previous lessons and results come together in a workable production package that can direct shop floor actions, so that we clearly understand and control what we must do to meet the customer's expectations and the warfighter's needs.

Slide 13: In-family Management

Statistical process control, or SPC, is key to achieving repeatability in our fuze products and processes. In-family management ensures that our processes and products are of consistent quality as opposed to simply being within specification. This means that only those products falling within the two sigma limits are automatically accepted. Products between two and three sigma are reviewed for acceptance, while those beyond three sigma we accept only on an exception basis. A step improvement in overall fuze repeatability will be achieved when we all realize that for these key products, for our military, just being within specification is not good enough.

A third quality improvement tool for the future is Process Owner Reviews. This simple yet powerful concept makes systematic the periodic review of the overall production process. All changes, no matter how insignificant, are analyzed and discussed before incorporation into fuze production. There is no such thing as a small change.

In-family management and process owner reviews help ensure repeatability. They provide a basis for each of our respective organizations to build on, both separately and in cooperation. Our path to excellence can be summarized in three words: communication, cooperation, and control. Communication in jointly defining, understanding, and documenting fuze requirements that meet the users' needs. Cooperation in working together on IPTs to ensure that the user's requirements are implemented in robust fuze designs. Control, in establishing and maintaining disciplined fuze manufacturing processes.

Commander Dahlgren complained in 1856 that "no advocate of any particular fuze could say more than 'it will fail in fewer cases than any other.'" No worse than the other guy. He was irritated by this attitude and I don’t blame him. We must all commit ourselves to continuous improvement. We need to build on the accomplishments and lessons learned from our predecessors, and leave clear markers for our successors on the path to perfect quality.

Slide 14: MR never-makes-a-dud

With apologies to Gary Larson, I leave you with this thought. Mr. Never-Makes-a-Dud may know the secret to perfect quality, but he should share that knowledge to create a repeatable process for the industry.

I have great respect for the creative, intelligent, dedicated people in the fuze business, many of whom are at this conference. I know you are as determined as I am to deliver high performance, repeatable, reliable fuzes to our kids, whose lives rely on that reliability.

Thank you.